Automating RF Circuit Synthesis
EE4902 Presentation

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Motivation

- Role of a Designer
- Advantage of ML
- Why this project

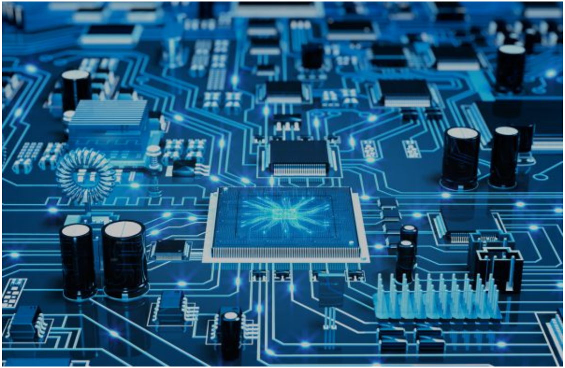


Figure: Ref : Automation Intellect

Algorithm

(1) Select the particular topology
(2) Design the schematic in Cadence
(3) Select the operating point. The local minima is highly influenced by the point chosen.
(4) Extract out the netlist
(5) Run the code specific to the netlist.
(6) Run the sensitivity and PVT analysis on the netlists that have loss below a certain threshold.
(7) Pick the netlist that satisfies the constraint on loss, sensitivity and PVT variations.

Gradient Descent

(1) Pick a starting point

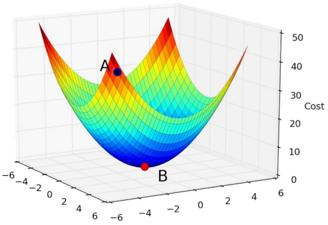
(2) Repeat until loss decreases in all dimensions

   (a) Pick a direction

   (b) Move incrementally in that direction

$$w_j = w_j - \eta \frac{d}{dw_j} loss(w)$$

where η is the popular **learning rate**



Loss/ Objective Function

The objective function is a linear combination of the following

(1) Gain Loss := ReLU(Gain specfication - Gain simulated)

(2) IIP_3 Loss := ReLU(IIP_3 specification - IIP_3 simulated)

(3) S_{11} Loss := ReLU(S_{11} simulation - S_{11} specification

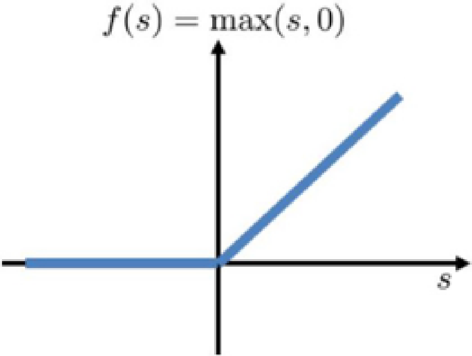
(4) I_{dd} Loss := ReLU(I_{dd} simulation - I_{dd} specification

(5) NF Loss := ReLU(NF simulation - NF specification

$$\text{Loss} = \alpha_1 \text{ Gain Loss} + \alpha_2 \; IIP_3 \text{ Loss} + \alpha_3 \text{ NF Loss} + \alpha_4 \; S_{11} \text{ Loss} + \alpha_5 \; I_{dd} \text{ Loss}$$

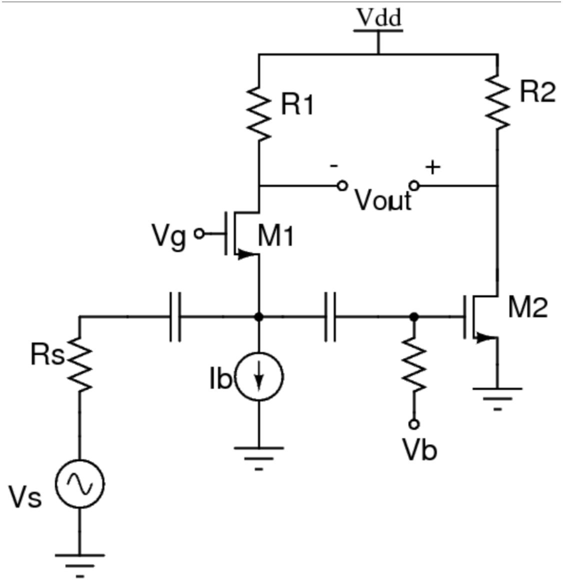
ReLU Activation

$$ReLU(x) = max\{x, 0\}$$



Rectified Linear Unit

Noise Cancelling LNA - Schematic



Noise Cancelling LNA - Small Signal Analysis

(1) S_{11} Expression

$$Z_{in} = \frac{1}{g_{m1}} = R_s = 50\Omega; S_{11} = \frac{Z_{in} - R_s}{Z_{in} + R_s}$$

(2) Noise Cancellation Condition

$$g_{m1}R_1 = g_{m2}R_2$$

(3) Gain Expression

$$\frac{V_{out}}{V_{in}} = g_{m1}R_1 = g_{m2}R_2$$

(4) Expression for Noise Figure

$$NF = 1 + \frac{R_s}{R_1} + \gamma\frac{R_2}{R_1} + \frac{R_s R_2}{R_1^2}$$

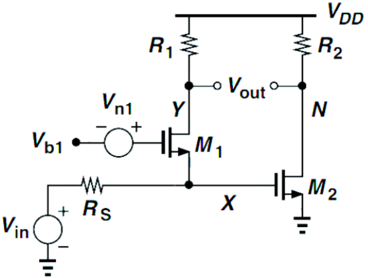


Figure: Noise Cancelling LNA

Noise Cancelling LNA - Update Equations

If Gain Loss > 0:

$$R_1 \leftarrow R_1 + \alpha_1; R_2 \leftarrow R_2 + \alpha_1$$

If NF Loss > 0:

$$R_1 \leftarrow R_1 - \alpha_2; R_2 \leftarrow R_2 - \alpha_2$$

If I_{dd} Loss > 0:

$$m_s \leftarrow m_s + \alpha_1; m_g \leftarrow m_g + \alpha_1$$

If S_{11} Loss > 0:

$$m_g \leftarrow m_g + \alpha \frac{20}{m_g - 5}$$

If IIP_3 Loss > 0:

$$m_s \leftarrow m_s - \alpha_2; m_g \leftarrow m_g - \alpha_2$$

where α, α_1 and α_2 are tunable hyperparameters called the **learning rate**(s).

Results

```
ee21b019@ams117~/EE4902/NoiseCancellingLNA/Demo> 50: python NCLNA.py
Parameters are {'ms': 20.0, 'mg': 80.0, 'R2': 500.0, 'R1': 200.0, 'Ib2': 0.0009,
 'Ib1': 9.999999999999999e-06, 'VDD': 0.9, 'circ_temp': 27.0, 'frf': 1000000000.
0, 'prf': -40.0}
The DC operating point is :
 Common Gate DCOP - gm : 0.008272424 S, gds : 0.0006486449 S, VDSAT : 0.1174172V

 Common Source DCOp - gm : 0.02004698 S, gds : 0.0026513 S, VDSAT : 0.1138974V.
 The current drawn from VDD is Idc = 0.001322653A
 The power consumed is 0.0011903877 W
The AC gain at 1000000000.0 (in dB) is 15.825028840279941
The NF (in dB) at 1000000000.0 is 5.107236
The S11 (in dB) at 1000000000.0 is -17.5354 and the S21 (in dB) is 16.8219
IIP3 for a Input power of -40.0 is -7.084839398354831 dBm
The value of loss is 2.1085586530000002
```

Figure: Starting Netlist

```
sh-5.1$ tcsh
ee21b019@ams117~/EE4902/NoiseCancellingLNA/Demo> 50: python NCLNA.py
Parameters are {'ms': 107.0, 'mg': 167.0, 'R2': 500.0, 'R1': 200.0, 'Ib2': 0.0009, 'Ib1': 9.999999999999996e-06, 'VDD': 0.9,
'circ_temp': 27.0, 'frf': 1000000000.0, 'prf': -40.0}
The DC operating point is :
 Common Gate DCOP - gm : 0.02589568 S, gds : 0.002214337 S, VDSAT : 0.1140186V
 Common Source DCOp - gm : 0.02181379 S, gds : 0.003343131 S, VDSAT : 0.1127661V.
 The current drawn from VDD is Idc = 0.002073518A
 The power consumed is 0.0018661662 W
The AC gain at 1000000000.0 (in dB) is 18.937782761891576
The NF (in dB) at 1000000000.0 is 2.791482
The S11 (in dB) at 1000000000.0 is -13.8161 and the S21 (in dB) is 19.4971
IIP3 for a Input power of -40.0 is -3.848847164256057 dBm
The value of loss is 0.002073518
```

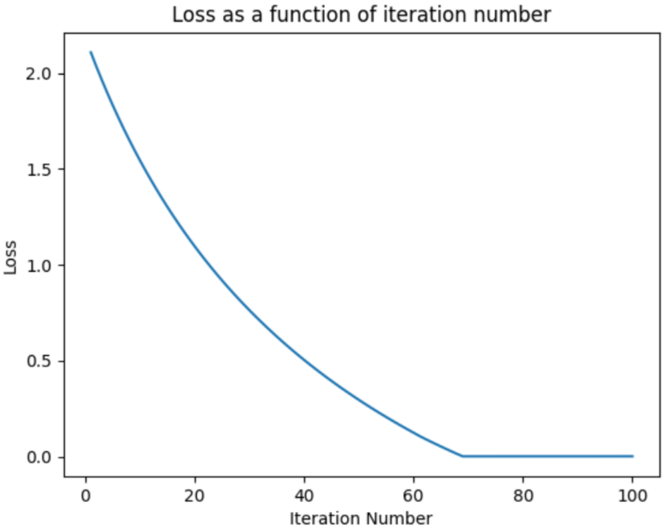
Figure: "Best" Netlist

Noise Cancelling LNA - "Best" Netlist

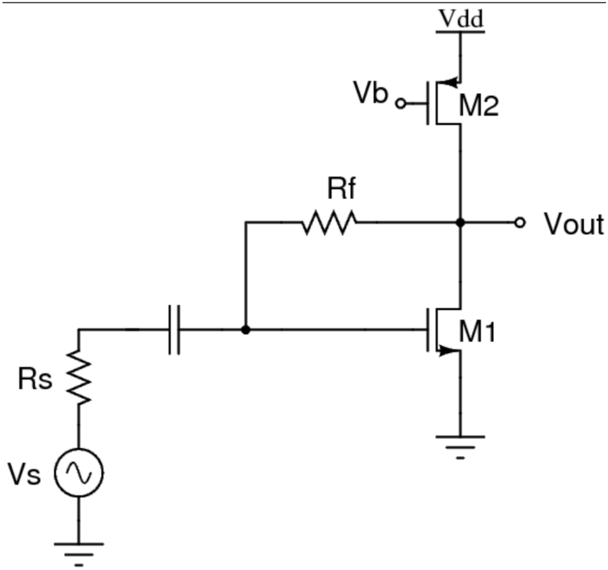
```
ee21b019@ams117~/EE4902/NoiseCancellingLNA/Demo> 51: python NCLNA.py
For Netlist 0, the analysis is done below -
The loss at -40 degree C is 0.001938817
The loss at 0 degree C is 0.001970255
The loss at 27 degree C is 0.001990783
The loss at 100 degree C is 1.3920957329999992

The loss at TOP_TT process is 0.001990783
The loss at TOP_FF process is 0.002053277
The loss at TOP_FS process is 0.002039875
The loss at TOP_SF process is 0.07775088300000009
The loss at TOP_SS process is 0.139516461

The loss at 0.81V is 0.006894246000000107
The loss at 0.9V is 0.001990783
The loss at 0.99V is 0.002081644

Sensitivity is 1.3926999999999995e-05
Temperature Sensitivity is 2.0400000000017626e-07
ee21b019@ams117~/EE4902/NoiseCancellingLNA/Demo> 52:
```

Figure: Sensitivity and PVT Variations

Loss - Noise Cancelling LNA



Resistive Feedback LNA - Schematic



Resitive Feedback LNA - Small Signal Analysis

(1) S_{11} Expression

$$Z_{in} = \frac{1}{g_{m1}} = R_s = 50\Omega$$

$$S_{11} = \frac{Z_{in} - R_s}{Z_{in} + R_s}$$

(2) Gain Expression

$$\frac{V_{out}}{V_{in}} = \frac{1 - g_{m1}R_f}{1 + g_{m1}R_s} \approx -\frac{R_f}{R_s}$$

(3) Expression for Noise Figure

$$NF \approx 1 + 4\frac{R_s}{R_f} + \gamma + \gamma g_{m2}R_s$$

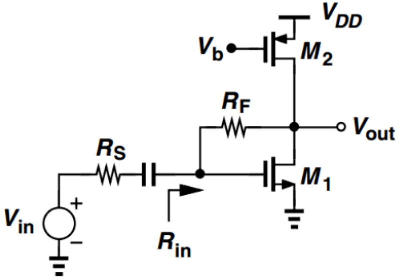


Figure: Resitive Feedback LNA

Resistive Feedback LNA - Update Equations

If Gain Loss > 0:

$$R_f \leftarrow R_f + \alpha_1; m_1 \leftarrow m_1 + \alpha_1$$

If NF Loss > 0:

$$R_f \leftarrow R_f - \alpha_2$$

If I_{dd} Loss > 0:

$$m_1 \leftarrow m_1 + \alpha_1; m_2 \leftarrow m_2 + \alpha_1$$

If S_{11} Loss > 0:

$$m_1 \leftarrow m_1 + \alpha \frac{20}{m_g - 5}$$

If IIP_3 Loss > 0:

$$m_s \leftarrow m_s - \alpha_2; m_g \leftarrow m_g - \alpha_2$$

where α, α_1 and α_2 are tunable hyperparameters called the **learning rate**(s).

Results

```
ee21b019@ams117~/EE4902/ResistiveFeedbackLNA/Demo> 51: python RFLNA.py
The DC operating point is
 gm : 0.02190101 S, gds : 0.001843623 S and VDSAT = 0.125024 V.
 The current drawn from VDD is Idc = 0.0014307 A
 Power Dissipated is 0.0012876300000000001 W
The AC gain at 1580000000.0 (in dB) is 9.118456218389866
The NF (in dB) at 1580000000.0 is 4.802808
The S11 (in dB) at 1580000000.0 is -12.9387 and the S21 (in dB) is 10.8638
IIP3 for a Input power of -40.0 is -10.350428333446441 dBm
The value of loss is 1.6857824816101334
```

Figure: Starting Netlist

```
sh-5.1$ tcsh
ee21b019@ams117~/EE4902/ResistiveFeedbackLNA/Demo> 50: python RFLNA.py
The DC operating point is
 gm : 0.01693128 S, gds : 0.001437814 S and VDSAT = 0.1187204 V.
 The current drawn from VDD is Idc = 0.0009421553 A
 Power Dissipated is 0.00084793977 W
The AC gain at 1580000000.0 (in dB) is 12.790373956174179
The NF (in dB) at 1580000000.0 is 3.693218
The S11 (in dB) at 1580000000.0 is -20.2214 and the S21 (in dB) is 13.3612
IIP3 for a Input power of -40.0 is -14.267927442457559 dBm
The value of loss is 0.0009421553
```

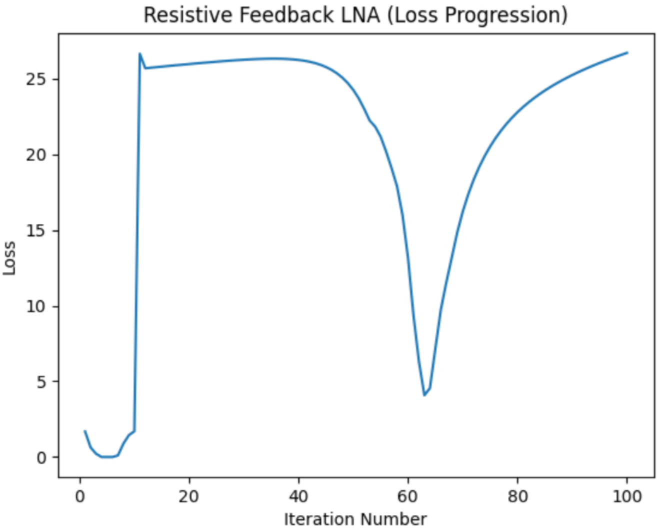
Figure: "Best" Netlist

Resistive Feedback LNA - "Best" Netlist

```
Temperature Sensitivity is 5.282000000000333e-07
ee21b019@ams117~/EE4902/ResistiveFeedbackLNA/Demo> 51: python RFLNA.py
For Netlist 0, the analysis is done below -
The loss at -40 degree C is 0.19854634507161945
The loss at 0 degree C is 0.0008786305
The loss at 27 degree C is 0.0009421553
The loss at 100 degree C is 0.3666076430000001

The loss at TOP_TT process is 0.0009421553
The loss at TOP_FF process is 0.001318576
The loss at TOP_FS process is 0.0008671747
The loss at TOP_SF process is 0.001031206
The loss at TOP_SS process is 0.43451564890000005

The loss at 0.81V is 0.04293915619999983
The loss at 0.9V is 0.0009421553
The loss at 0.99V is 0.001157762

Sensitivity is 1.6298500000000047e-05
Temperature Sensitivity is 5.328000000000841e-07
ee21b019@ams117~/EE4902/ResistiveFeedbackLNA/Demo> 52:
```

Figure: Sensitivity and PVT Variations

Loss - Resistive Feedback LNA



Key Statistics

Property	**Noise Cancelling**	**Resistive Feedback**
Number of Iterations	100	100
Netlists passed Optimization	68	12
Netlists passed the PVT	32	3
Netlists passed Sensitivity	10	3
Lowest Loss Obtained	0.00199	0.0010
Sensitivity	$1.392 \text{x} 10^{-5}$	$1.6298 \text{x} 10^{-5}$

Table: Highlights

Finally : The "best" Noise Cancelling LNA Netlist

Requirement	Specification	Starting Point	Final Result
Gain	15 dB	15.82 dB	18.85 dB
Noise Figure	5 dB	5.107 dB	2.938 dB
S_{11}	-10 dB	-17.5354 dB	-14.51 dB
IIP_3	-10 dBm	-7.08 dBm	-5.22 dBm
Power	Minimize	1.322 mW	1.79 mW
Loss		2.108	0.00199

Table: Noise Cancelling LNA - Results

The sensitivity was evaluated to be 1.392x10^{-5} while the temperature sensitivity evaluated to be 2.04x10^{-7}. The time taken to run this code was about 35 minutes.

Finally : The "best" Resistive Feedback LNA Netlist

Requirement	Specification	Starting Point	Final Result
Gain	10 dB	9.11 dB	12.114 dB
Noise Figure	4 dB	4.80 dB	3.8133 dB
S_{11}	-10 dB	-12.94 dB	-18.8709 dB
IIP_3	-15 dBm	-10.35 dBm	-13.43 dBm
Power	Minimize	1.288 mW	0.95 mW
Loss		1.6857	0.0010

Table: Resistive Feedback LNA - Results

The sensitivity was evaluated to be 1.62985×10^{-5} while the temperature sensitivity evaluated to be 5.328×10^{-7}. The time taken to run this code was about 30 minutes.

Conclusion

- The role of a designer is crucial and irreplaceable.
- Faster and easier to reach optimum
- Highly dependent on the initial netlist
- Cannot "generate" a netlist

Thank You